AFRL-VS-TR-2001-1604

Strategic High Altitude Infrared Backgrounds

W.O. Gallery
H.E. Snell
J.-L. Moncet

Atmospheric and Environmental Research, Inc.
131 Hartwell Ave
Lexington, MA 02421

15 Jan 2001

Final Report

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

20030220 046

AIR FORCE RESEARCH LABORATORY
Space Vehicles Directorate
29 Randolph Rd
AIR FORCE MATERIEL COMMAND
Hanscom AFB, MA 01731-3010

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

d

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 15, 2001	Final Report, 10 June, 1993 - 28 February 1999

4. TITLE AND SUBTITLE
Strategic High Altitude Infrared Backgrounds

5. FUNDING NUMBERS
PE: 63215C
PR: S321 TA: GD WU: AD
Contract F19628-93-C-0040

6. AUTHOR(S)
W. O. Gallery, H. E. Snell and J.-L. Moncet

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)
Atmospheric and Environmental Research, Inc.
131 Hartwell Avenue
Lexington, MA 02412

8. PERFORMING ORGANIZATION REPORT NUMBERS
Project No. P-519

9. SPONSORING / MONITORING AGENCY NAMES(S) AND ADDRESS(ES)
Air Force Research Lab
29 Randolph Road
Hanscom AFB, MA 01731-3010
Contract Manager: Dean Kimball

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
AFRL-VS-TR-2001-1604

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

12b. DISTRIBUTION CODE

13 ABSTRACT (Maximum 200 words)
The purpose of this contract was to "...provide models and codes to predict infrared background phenomenon to be encountered by advanced space based systems operating in natural and disturbed backgrounds." The three specific tasks of the contact were: (1) analysis data from the Mid Course Space Experiment (MSX), (2) development of advanced radiance inversion techniques, and (3) enhancement of the radiative transfer program FASCODE Environment (FASE). Under (1), AER developed experiment plans and detailed data collection event parameters for MSX to obtain vertical profiles of radiance and trace gases in the stratosphere. In addition, AER analyzed data from meteorological satellites coincident with MSX measurements and correlated these data with the MSX data. In (2), AER collaborated with PL/GPOS to analyze radiance data from CIRRIS-II. by enhancing and applying the fast radiative transfer code XFWD and the inversion INV. In (3), AER continued the development of the atmospheric radiative transfer code FASCODE . The new code is called FASE, for FASCODE for the Environment.

14. SUBJECT TERMS
MSX, FASE, CIRRIS-II, FASE, FASCODE, Atmospheric radiance, Infrared, Backgrounds, Remote sensing, Inversion, Trace gases

15. NUMBER OF PAGES
9

16. PRICE CODE
Z

17. SECURITY CLASSIFICATION OF REPORT	18.SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

Table Of Contents

1. Introduction

As stated in the Phillips Lab PRDA, the goal of this contract is to "...provide models and codes to predict infrared background phenomenon to be encountered by advanced space based systems operating in natural and disturbed backgrounds." To accomplish this goal, the contract was initially divided into four tasks:

1. MSX Data Analysis

2.1 Trace Species in MODTRAN

2.2 Radiance Inversion Techniques

2.3 Mesospheric Radiance Model

The contract was amended in December 1994 to add a new task:

3. FASE (FASCODE Environment)

However, soon after the beginning of the contract, it was discovered that the work specified for Task 2.1 Trace Species in MODTRAN had already been performed by another contractor and no further work was performed on this task. Task 2.3 Mesospheric Radiance Model was never funded so no work was performed on this task either.

The following sections will describe briefly the work performed on the remaining three tasks and refer to reports and publications where the work is described in detail. These publications are listed in Section 5 by task.

2. MSX Data Analysis

The Midcourse Space Experiment (MSX) is a satellite experiment originally designed to measure the faint background radiance in the earth's limb against which targets are to be detected. The principal instrument on MSX was SPIRIT III, a solid-hydrogen cooled interferometer with six detectors covering bands from 1.6 micrometers to 12 micrometers at a maximum spectral resolution of 2 cm^{-1}. MSX also carried a suite of visible and ultraviolet imagers and imaging spectrometers UVISI and the broadband visible imager SBV. A complete description of MSX is given in Mill et al., 1994 and Mill 1997. MSX was launched on April 26, 1996. SPIRIT III provided data from May, 1996 to March 1997 when the cryogen ran out. The UVISI and SBV instruments continue to operate.

Between the time of the instrument design and launch, interest changed from the strictly upper altitude limb (above 40 km) to include lower altitude limb (0 to 40 km) and below-the-horizon (BTH) backgrounds. In addition, it was realized that during the lifetime of MSX (originally projected to be between Nov., 1994 and May, 1996) it would be the only satellite capable of measuring trace gases in the stratosphere and would bridge the gap between the Upper Air Research Satellite (UARS) and the Earth Observation Satellite (EOS). AER's work was an extension of the work performed on a previous contract: "Development of Remote Sensing Algorithms for Atmospheric Variables from Radiometer Data-Phase II", Contract No F19628-91-C-0167, [Gallery and Moncet, 1994.]

AER's responsibility in the MSX program was to:

1. Prior to launch, prepare experiment plans for MSX observations of the low altitude limb, both for general surveys and for the retrieval of stratospheric trace gases,
2. During the cryogen phase (SPIRIT III is operating), prepare detailed monthly plans for data collection events (DCE's) for the experiments in 1.,
3. Develop the software for the automated analysis of the data from the UVISI sensors,
4. Provide for the analysis of auxiliary data from complementary sources, specifically, from weather satellites, to support the analysis of MSX data

AER created the following MSX experiment plans:

- ELE-4: Airglow Staircase Survey
- ELE-10: Vertical Profile Survey
- ELE-19: Stratospheric Trace Gas Survey

Early versions of these experiment plans were reported in Gallery and Moncet, 1994.

Detailed monthly plans for the DCE's belonging to these experiment plans were reported in Annual Scientific Report II, Gallery et al., 1998.

The development of the software for the automated analysis of the UVISI data was also reported in Annual Scientific Report II, Gallery et al., 1998. This software was delivered to the PL DAC in 1995.

Analysis of auxiliary data has been reported in numerous publications listed in Section 5.2. The most notable papers are: Picard et al., 1998, and Dewan et al., 1998.

3. Radiance Inversion Techniques

This task involved the development and testing of radiance inversion techniques that could be used to determine atmospheric physical and chemical properties from remotely sensed data. In particular, algorithms were developed to derive atmospheric trace gas amounts from radiometric data collected by the CIRRIS-1A experiment. CIRRIS-1A was flown aboard the Space Shuttle Discovery as part of the STS-39 payload in April 1991, and details may be found in [Ahmadjian et al., 1990].

AER's responsibility in the development of the retrieval algorithm included:

1. The development of a fast, accurate radiative transfer code to be used as part of the overall radiance inversion package.
2. The development of a robust inversion routine to estimate geophysical parameters from the measured radiances.
3. All design, implementation and testing of the algorithm modules.
4. Running of test cases with both simulated and real data.
5. Transfer of the retrieval algorithm to Dr. Steven Miller at Hanscom.
6. Provide expertise and results for technical papers and presentations.

The radiative transfer code ("XFWD") was developed from FASCODE and leveraged AER resources from other projects. The inversion module ("XINV") was based on Rodgers' (1976) optimal inversion technique. Simulations were done for a variety of scenarios, including

the limb-viewing geometry applicable for CIRRIS-1A. The results of these tests are documented in two refereed journal papers (Miller et al., 1999; Miller et al., 2000).

4. FASE

This task involved working directly with Gail Anderson (AFRL, Hanscom) to continue the development of the FASCODE radiative transfer algorithm. This new version was dubbed "FASE" (FASCODE for the Environment). The details of this algorithm and our effort on this task are described in Snell et al., 2001.

5. References

5.1 Annual Scientific Reports

Year Report

1. Gallery, W. O., J.-M. Moncet, and H. E. Snell, 1998, Strategic High Altitude Infrared Backgrounds, Annual Scientific Report Number 1 for Contract No. F19628-93-C-0040, covering the period10 June, 1993 - 31 June, 1994, AFRL-VS-HA-TR-98-0127, 23 October, 1998
2. Gallery, W. O., J.-M. Moncet, and H. E. Snell, 1998, Strategic High Altitude Infrared Backgrounds II, Annual Scientific Report Number 2 for Contract No. F19628-93-C-0040, covering the period 1 July, 1994 - 31 June, 1995, 23 October, 1998
3. Gallery, W. O. and H. E. Snell, 1998, Strategic High Altitude Infrared Backgrounds III, Annual Scientific Report Number 3 for Contract No. F19628-93-C-0040, covering the period 1 July, 1995 - 31 June, 1996,
4. (See Picard et al., 1998, under MSX)
5. (See Snell, et al., 2001, under FASE

5.2 MSX

Dewan, E. M., R. H. Picard, R. R. O'Neil, H. H. Gardiner, J. Gibson, H. D. Mill, E. Richards, J. Kendra, and W. O. Gallery, 1998, MSX Satellite Observation of thunderstorm-generated gravity waves in mid-wave infrared images of the upper stratosphere, *Geophy. Res. Lett.*, **25**, 939-942

Fraser, M., W. Gallery, T. Opar, G. Romick, D. Anderson, D. Morrison, M. Kendra, R. Hegblom, H. Gardiner, R. O'Neil, 1997, "MSX: The Aurora of 10 November 1996 Observed Over Scandinavia", Spring Meeting American Geophysical Union, Baltimore MD, 27-30 May 1997, (paper SA42B-07)

Gallery, W. O., J.-L. Moncet, 1994, "Development of Remote Sensing Algorithms for Atmospheric Path Variability From Radiometer Data", PL-TR-94-2263.

Gallery, W. O., H. Snell, C. Sarkiasian, D. Hogan, A. Zachor, and J. Winick, 1997, "FASE-Calculated Contribution and Sensitivity Functions for MSX SPIRIT III MWIR Bands for BTH Measurements", 20th Annual Review Conference of Atmospheric Transmission Models, Phillips Laboratory, Geophysics Directorate, Hanscom AFB, June 10-12, 1997

Mill, J. D., R.R. O'Neil, S. Price, G.J. Romick, O.M Uy, E.M. Gasposchkin, G.C. Light, W.W. Moore, Jr., T. L. Murdock, A.T. Stair, "The Midcourse Space Experiment: An Introduction to Spacecraft, Instruments and Scientific Objectives", *Journal of Spacecraft and Rockets,* **Vol. 31, No. 5**, September-October 1994

Mill, J. D., 1997, Overview of the Midcourse Space Experiment (MSX), EOS, Proceedings American Geophysical Union, Vol. 78 (17), Paper No. SA41B-01, May 27-30, 1997

O'Neil, R. R., H. A. Gardiner, A. S. Zachor, W. Gallery, M. E. Fraser, M. Kendra, A. T. Stair, 1997, "Midcourse Space Experiment (MSX): Terrestrial Clutter in the MWIR from Spectral Data", 1997 IRIS Specialty Group Meeting on Targets, Backgrounds and Discrimination, Naval Postgraduate School, Monterey, CA, February 4-6, 1997, Paper B-4

Picard, R. H. , R. R. O'Neil, H. A. Gardiner, J. Gibson, J. R. Winick, W. O. Gallery, A. T. Stair, Jr, P. P. Wintersteiner, E. R. Hegblom, and E. Richards, 1998, Remote sensing of discrete stratospheric gravity-wave structure at 4.3-μm from the MSX satellite, *Geophys. Res. Lett*, **25**, 2809-2812

Shanks, J. G., F. R. Waugh, A. Dudkin, R. R. O'Neil, H. A. B. Gardiner, W. A. M. Blumberg, E. R. Hegblom, B. Sullivan, M. J. Kendra, W. O. Gallery, 1999, "MSX Observations of Solar Glint In The MWIR: Analysis and Implications For Surveillance Systems", 1999 Meeting of the IRIS Specialty Group on Missile Defense Sensors, Environments and Algorithms, 26-28 January 1999, Naval Post Graduate School. Monterey, CA

Wintersteiner, P., M. Kendra, D. Strickland, G. Romick, D. Morrison, R. O'Neil, H. Gardiner, W. Gallery, M. Fraser, 1997, "MSX: Auroral Visible and Ultraviolet Emissions", Spring Meeting American Geophysical Union, Baltimore MD, 27-30 May 1997, (paper SA42B-08)

Zachor, A. S., W. O. Gallery, R. R. O'Neil, J. Gibson, H. A. B. Gardiner, A. T. Stair jr., and J. D. Mill, 1994, "Mid-course Space Experiment (MSX): Capabilities of the LWIR Interferometer for Remote Sensing of Trace Constituents in the Stratosphere and Mesosphere", Proceedings of SPIE International Symposium of Optical Engineering in Aerospace Sensing, Orlando, FL, April 4-8,1994

Zachor, A., R. R. O'Neil, H. Gardiner, J. J. Gibson, W. Gallery, M. Kendra, T. Woolstan, and A. T. Stair, 1997, "Midcourse Space Experiment (MSX): MWIR Spectral Studies of BTH Clutter", Space Surveillance Meeting, JHU/APL, 4-5 June 1997. (Paper A-2)

5.3 Radiance Inversion Techniques

Ahmadjian, M., R.M. Nadile, J.O. Wise, and B. Bartschi, 1990, CIRRIS-1A space shuttle experiment, *J. Spacecr. and Rockets*, *27*, 669-674, 1990.

Miller, S., J.R. Winick, and H.E. Snell, 2000, Non-LTE Effects on Retrieval of Temperature from the CO2 Laser Bands Using CIRRIS-1A Data, *J. Geophys. Res.*, *105*, 10193-10202, 2000.

Miller, S., H.E. Snell, and J.-L Moncet, 1999, Simultaneous Retrieval of Middle Atmospheric Temperature and Trace Gas Species Volume Mixing Ratios from Cryogenic Infrared Radiance Instrumentation for Shuttle (CIRRIS-1A), *J. Geophys. Res.*, *104*, 18,697-18,714, 1999.

5.4 FASE

Anderson, G.P., J.H. Chetwynd, A. Berk, L.S. Bernstein, P.K. Acharya, H.E. Snell, and E.P. Shettle, MODTRAN4: Simulating Atmospheric Radiation for Cloudy Conditions, NATO Publication RTO-MP-1, 1998.

Snell, H.E., G.P. Anderson, J.H. Chetwynd, and S. Miller, FASE/FASCOD4: Current Status and Future Direction, in *Proceedings of the 20th Annual Conference on Atmospheric Transmission Models*, Hanscom AFB, MA, 10-12 June 1997, ADA 347 476

Snell, H.E., G.P. Anderson, A. Berk, P. Acharya, and L. Bernstein, Spectral Resolution Effects on Solar Irradiance Calculations, in *Proceedings of the Seventh Atmospheric Radiation Measurement (ARM) Science Team Meeting*, San Antonio, Texas, 3-7 March 1997.

Snell, H.E., W.O. Gallery, D.B. Hogan, J.-L. Moncet, G.P. Anderson, J.H. Chetwynd, S. Miller, and J. Wang, FASCODE for the Environment (FASE), in *Proceedings of the Sixth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, San Antonio, Texas, 4-7 March 1996.

Snell, H.E., G.P. Anderson, J. Wang, J.-L. Moncet, J.H. Chetwynd, and S.J. English, Validation of FASE (FASCODE for the Environment) and MODTRAN3: Updates and Comparisons with Clear-Sky Measurements, *The European Symposium on Satellite Remote Sensing, Conf. of Passive IR Remote Sensing of Clouds and the Atmosphere III,* Paris, France, 24-27 September 1995.

Snell H.E., J.-L. Moncet, G.P. Anderson, J.H. Chetwynd, and S. Miller, "FASCODE for the Environment (FASE)", *SPIE Proceedings, 2471: International Conference on Atmospheric Propagation and Remote Sensing IV*, Orlando, FL, 17-19 April 1995.

Snell, H. E., W.O. Gallery, J.-L. Moncet and C.P. Sarkisian, (in press), FASCODE for the Environment (FASE), AFRL-VS-TR-2001-1603, 2001, ADA 402 150